Advances in Materials Research: An Internship at Kennedy Space Center

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My time at Kennedy Space Center was spent immersing myself in research performed in the Materials Science Division of the Engineering Directorate. My Chemical Engineering background provided me the ability to assist in many different projects ranging from tensile testing of composite materials to making tape via an extrusion process. However, I spent the majority of my time on the following three projects: (1) testing three different materials to determine antimicrobial properties; (2) fabricating and analyzing hydrogen sensing tapes that were placed at the launch pad for STS-133 launch; and (3) researching molten regolith electrolysis at KSC to prepare me for my summer internship at MSFC on a closely related topic. This paper aims to explain, in detail, what I have learned about these three main projects. It will explain why this research is happening and what we are currently doing to resolve the issues. This paper will also explain how the hard work and experiences that I have gained as an intern have provided me with the next big step towards my career at NASA.

Nomenclature

AODC	=	Acridine Orange Direct Counts
CDC	=	Center for Disease Control
HPC	=	Heterotrophic Plate Counts
KSC	=	Kennedy Space Center
LN_2	=	Liquid Nitrogen
MOE	=	Molten Oxide Electrolysis
MSFC	=	Marshall Space Flight Center
NASA	=	National Aeronautics and Space Administration
O_2	=	Oxygen gas
PDMS	=	Polydimethylsiloxane
PdO	=	Palladium (II) oxide
PSIG	=	Pounds per square inch (gauge)
R2A	=	R2 Agar
RTV	=	Room Temperature Vulcanization
SRB	=	Solid Rocket Booster
STEM	=	Science, Technology, Engineering, and Mathematics
STS	=	Space Transportation System
TiO_2	=	Titanium dioxide
TSM	=	Tail Service Mast

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Prologue

Rocket Scientist. Space Shuttle. Astronomer. The Moon. The Universe. Monkeys. Those are a few thoughts that pass through children's brain when the word "NASA" is presented to them. Sure NASA consists of a lot more than those few topics, but as a child, they do not know much more than what they learn in a history or science class. At the elementary and middle school level, an interest develops in the sciences and a select few students will continue their life pursuing a career in a STEM related field. However, a majority of these students will move onto high school and eventually college to realize that the STEM field requires a lot more work than other fields. This deters many students away from pursuing their interests in science. It is my goal to inspire students to pursue their dreams, much like I am doing now, and that hard work, persistence, and determination pays off in the long run.

I realized all of this about children in recent education outreach events that I participated in. One of the most notable outreach events I did happened prior to the beginning of my internship at KSC. Before leaving for Florida, I went and spoke to a group of 8th graders about how I am living my dreams and working towards my ultimate goal of one day permanently working for NASA. I spoke to them about NASA in general, how I got interested in NASA, and how I work every day to make sure my dreams become a reality. At the beginning of my presentation, I had multiple questions asking various things ranging from if I have any friends, if I have anytime to play sports, etc. They assumed that because I am studying chemical engineering that I only study, nothing else. The term "engineering" intimidates a lot of people, so I reassured them that even though I spend a great deal of time during school studying and applying myself towards my goals, I do in fact have friends and that I have a social life outside of school. I explained to them my involvement with a sorority, my regular workout schedule, my volunteering activities, and my general hanging out with my friends. They were all very surprised that I did all of this. I even heard from multiple students that although they like their science classes a lot, they would never want to do it forever because it takes up too much time and they wouldn't have a life. I think after telling my story, I changed a lot of their minds because after this revelation, I was bombarded with questions regarding science and NASA. I was asked things like "How do the shuttles lift off?", "What is chemical engineering?", "What does NASA do?", "How do I become an astronaut?", "How do I become the owner of NASA?", and my personal favorite, "Can I send a monkey into space?" All of these questions showed me that I somehow had inspired these kids enough to make them think about science and NASA, even if it was just for that day. However, I know that I made a bigger impact than I had expected. I have kept the principal of that school up-to-date with all my wonderful adventures as a KSC intern, including pictures and postcards. She has been showing them to her students and has told me that they can't wait for me to come back and tell them about what I have done. This is one of the most rewarding experiences I have had thus far in my life, and it has definitely gave me an extra edge to continue pushing harder than ever to pursue my lifelong dream of working for NASA.

My time as a KSC intern this past spring has provided me with the next big step in my pursuit of having a job at NASA when I graduate college. It has allowed me to receive an internship position at Marshall Space Flight Center through the NASA Academy program. This summer at MSFC I will be expanding my knowledge on In-Situ Resource Utilization by designing a prototype system that will perform molten oxide electrolysis using ionic liquids.

Chapter 1: Antimicrobial Materials in Water Treatment Systems

I.   Introduction

This project was performed under a Non-Disclosure Agreement and Space Act Agreement KCA-4240, so all materials have been given alternative labels to meet Sensitive But Unclassified (SBU) requirements.

The human body is composed of a very high percentage of water; approximately 70 % depending on the person. Therefore, it is makes sense that water is a very crucial element in any manned spaceflight mission. The astronauts onboard the spacecraft utilize water in a wide variety of ways ranging from rehydrating food and beverages for consumption to plain drinking water to personal hygiene tasks. On a daily basis, one crew member will use over 5 kg of potable water (6.6 pounds) for rehydration efforts and drinking water alone. An even greater amount of water will be used when personal hygiene tasks are added into the equation. In order to provide a sufficient supply of water to the astronauts, NASA has set the following water supply standards[6] for manned spaceflight:

> Potable Water (for consumption): 5.68 – 8.0kg water/ person-day
> Personal Hygiene: 37.03 kg water/ person-day

These numbers verify how impractical it would be to try and re-supply the spacecraft with the total amount of water for the duration of a mission. The water would begin to add a great deal of weight to the spacecraft and would occupy too much room. Therefore, for any type of manned spaceflight mission (long or short duration), water must be able to be recycled and made potable from within a closed-loop system. When water is recycled, there is an increased potential for the growth of pathogenic and opportunistic organisms, which could compromise the astronaut's health. Currently, microbial growth is controlled by using chemical biocides, either iodine or ionic silver, in order to decontaminate the water[6]. Although both materials have provided sufficient microbial control, they have their disadvantages. These chemicals have low human toxicity thresholds and require multiple doses (a re-supply) to remain effective as their antimicrobial potency decreases over time. It is for these reasons that NASA has begun investigations into new antimicrobial methods.

At Kennedy Space Center, one method of proposed microbial control involves applying an antimicrobial material coating to the interior surface of a water system. In order to investigate this newly proposed method, experimentation on the log reduction of the microbe, *Pseudomonas aeruginosa* (strain ERC1) was performed using the Center for Disease Control (CDC) High Shear Bioreactor.

Three different antimicrobial materials (Antimicrobial A, B, and C) were used in conjunction with two different polymer coupons, polydimethylsiloxane (PDMS) and acrylic, in order to perform the necessary tests. All of the coupons used during experimentation were uniform in size with a 12 mm diameter. The polymers were used for imprinting of a surface topography to mimic the microbe-resistant properties found in nature.

II.   Materials and Methods

In order to test the three different antimicrobial materials, ASTM E 2562-07 Method "Standard Test Method for Quantification of *Pseudomonas aeruginosa* Biofilm Grown with High Shear and Continuous Flow using CDC Biofilm Reactor" was followed.

The CDC reactor can hold eight rods, each rod containing spots for three removable coupons for sampling purposes providing a maximum of 24 sampling points for each trial. Figure 1 shows an illustration of the CDC Biofilm Reactor[1]. To prepare for each trial, the reactor was sterilized using ethylene trioxide (ETO) a minimum of 10 days prior to the start date of the trial. This 10 day time period was necessary for the reactor to release any trapped gas that may have accumulated. Using an environmental control chamber, the reactor was maintained at a temperature of $21 \pm 2°C$, a relative humidity of 50%, 400 ppm of CO_2, and no light during all trials.

Figure 1. CDC Biofilm Reactor

All coupons used during each trial were uniform round, 12 mm diameter disks. Each trial period consisted of 18 samples: 3 smooth coupons with no antimicrobial, 3 patterned coupons with no antimicrobial, 6 smooth coupons with the antimicrobial, and 6 patterned coupons with the antimicrobial.

The microbe used during all trials was *Pseudomonas aeruginosa*, strain ERC1. *Pseudomonas aeruginosa* was plated onto aseptic R2A plates using the streak plating method (Fig. 2). This method grows individual colonies to be
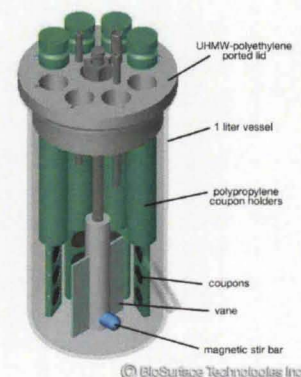
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used to prepare the microbe for placement into the reactor. To prepare the microbe for the reactor, 50 mL of 900 mg/L TSB was added to three different flasks. One of the three flasks remained blank (no addition of the microbe) in order to verify there was no contamination in the TSB media. One colony of *Pseudomonas aeruginosa* was added to each of the two remaining flasks. The three flasks were then incubated in a stirring incubator for 24 hours at 37°C.

After 24 hours, the optical density of the microbe solution is taken at 590 nm. For testing purposes, a microbe concentration of 1×10^8 cells/mL was desired. The resulting concentration immediately after removal from the incubator is generally higher that what is desired. A conversion takes place to obtain the desired concentration by using the following formula:

$$C_1 V_1 = C_2 V_2$$

Where C_1 is the initial concentration found by determining the optical density, V_1 is the unknown volume of microbe, C_2 is the desired concentration, and V_2 is the desired volume needed for the reactor.

Figure 2. Streak Plating Method

To prepare the reactor for each trial, 300 mg/L of TSB wass poured directly into the reactor. Then, 1 mL of the 1×10^8 cells/mL concentration of *Pseudomonas aeruginosa* was inserted into the reactor by using a feed tube. Following this insertion, the feed tube is rinsed with 1mL of sterile water, resulting in a final concentration of *Pseudomonas aeruginosa* inside the reactor of 2×10^5 cells/mL. The reactor was then placed on a stir plate at 130 rpm for 24 hours. This was the batch phase of the trial. During the batch phase, there is no flow through the reactor. The only shear that is present comes from the stir plate. These are the optimal biofilm growth conditions. Following this 24 hour time period, the reactor began to operate in its continuous flow phase where the carbon source (100mg/L TSB) flowed into the reactor via a peristaltic pump at 11.7 mL/min. The entire set up for the reactor can be seen in Fig. 3[1].

Harvesting of the coupon samples was done following this full 48-hour test period. The material samples were removed from the coupons using a small pair of forceps and rinsed with 10 mL of sterilized water (5 mL on each side of material sample). Each sample was then placed in a tube containing 3 mL of PBS (pH of 7.4). The biofilm was suspended in solution by vortexing the sample tubes and sonicating them.

Quantifying the amount of viable cells after the reactor ended was completed by using two methods: Heterotrophic Plate Counts (HPC) on R2A and Acridine Orange Direct Count (AODC). A serial dilution, carried out to a -5 dilution, took place prior to beginning the HPC procedures. Each dilution was a 1:100 ratio. 100 μL of the -2, -3, and -4

Figure 3. Reactor set-up

dilutions were plated onto aseptic R2A plates using the spread plating method. These plates were then placed in an incubator at 37°C and grown for 24 hours. After the 24 hour period, plates were removed from the incubator and visually examined to determine which plate would produce a count with three significant figures. That plate with three significant figures was then selected and counted. The AODC was performed by dying 1 mL of the vortexed and sonicated sample with 100 μL of AO for 5 minutes. The dyed sample was then filtered through a black Millipore filter and dried. The dried sample filter was then placed onto a drop of oil that was present on a test slide. Another drop of oil was added on top of the dried sample filter and was covered with a cover slip. These samples were then observed using the Zeiss Epi-Fluorescent Axioskop Microscope. The images from the sample slides were saved using a DP Controller and DP Manager[2]. The count for viable cells was completed by using the Image-Pro Express 7.0 software. The sample counts obtained from this software had an approximate error of 5% associated with it. The AODC process does not discriminate between viable and non-viable cells, and the Image-Pro software cannot count individual cells that may be clumped together.

III. Discussion of Results

The inoculum levels from each reactor trial were quantified using both HPC and AODC. The numbers obtained from these methods verified that the reactors remained consistent between trials, producing sound results.
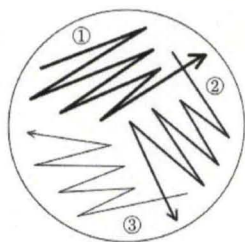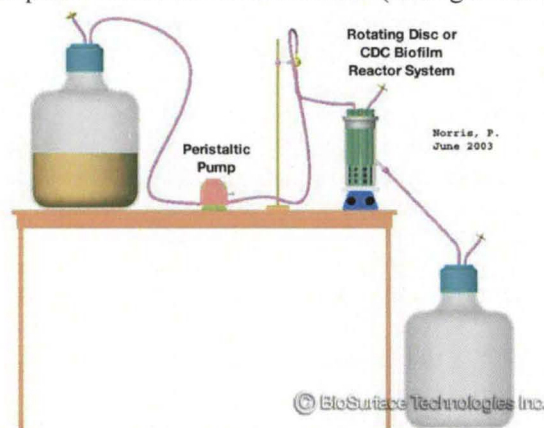
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In order to be considered a good antimicrobial material, a minimum 5 $\log_{10}$ reduction between the sample compared to the smooth control sample. From the data described below, none of the antimicrobial materials tested for this paper produced a large enough log reduction to be considered a material with good antimicrobial potential.

Of the three antimicrobial materials, Antimicrobial A is the material which shows the least promise. When Antimicrobial A was patterned, a 0.06 $\log_{10}$ reduction was observed when compared with the smooth control sample. When Antimicrobial A was not patterned, a reduction of 0.05 $\log_{10}$ was seen. When the sample was patterned but did not contain Antimicrobial A, only a reduction of 0.04 $\log_{10}$ was seen.

When comparing the numerical results obtained from the trials performed on Antimicrobials B and C, these materials looked as though they were almost identical in efficacies. Antimicrobial B and Antimicrobial C that had a pattern showed a 0.12 $\log_{10}$ and 0.39 $\log_{10}$ reduction, respectively. Antimicrobial B without a pattern showed a 0.23 $\log_{10}$ reduction and Antimicrobial C without a pattern showed a 0.28 $\log_{10}$ reduction. Finally, a patterned sample without the antimicrobial showed a 0.21 $\log_{10}$ reduction for Antimicrobial B and a 0.04 $\log_{10}$ reduction for Antimicrobial C. Future modifications could be made on Antimicrobial B to improve its antimicrobial properties because it is a newer material being investigated. Antimicrobial C, being an older material, does not show as much promise.

Chapter 2: Hydrogen Tape

I. Introduction

Hydrogen gas, a primary propellant for the launch of a space shuttle, is a colorless, odorless gas that has a lower explosion limit of approximately 4% in air[6]. A hydrogen leak is an incredibly dangerous scenario putting Shuttle personal at risk and potentially causing a launch delay until the problem is found and fixed. The most recent example of a delay due to the detection of a hydrogen leak was the attempted launch of Space Shuttle Discovery in November 2010. The detection of this leak was one of a few problems that caused Discovery's launch to be postponed to February 2011.

In order to assist in locating the exact site of a hydrogen leak and to better maintain the launch schedule, a color changing tape was developed. The idea was to use an irreversible chemochromic hydrogen sensing pigment that would change from beige to gray in an ideal situation. This pigment would then be incorporated into a silicone matrix that would be made into a thin tape to be applied at various flanges along the hydrogen lines that fuel the Space Shuttles. The pigment that was used in this study was prepared by plating palladium (II) oxide (PdO) onto titanium dioxide (TiO_2). The initial pigment is beige in color. When exposed to hydrogen gas, the palladium that is present reacted with the hydrogen gas and participated in a reduction reaction. Once the reduction reaction took place, the palladium was present in its metallic form where it is grey in color, causing a color change in the tape. The reaction just described is depicted below[5]:

$$PdO + H_2 \rightarrow Pd + H_2O$$
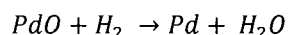
The hydrogen tape would be useless if it could not withstand the harsh effects of a launch. Before the tape could be deployed at the launch pad, it had to pass two different NASA/KSC standards, one for flammability (Test 1 of NASA-STD-(1)-6001A) and one for electrostatic discharge (KSC/MMA-1985-79). In addition to these two NASA standards, the tape used for final deployment had to be able to withstand the cryogenic temperatures experienced on the hydrogen lines during a launch as well as remain unaffected by UV radiation from the sun[8].

II. Previous Findings

In recent years, multiple studies were conducted at KSC on the development of hydrogen sensing materials. These studies led to crucial findings that guided researchers in their selection of materials and parameters. Some of the significant discoveries are described below.

Studies[5] were conducted to determine how the PdO particle size plated on various types of TiO_2 affected the chemochromic behaviors of the hydrogen sensing pigment. Based on a study of four different synthesized pigments, chemochromic activity was shown to be highly affected by the size of the PdO particles and how much agglomeration on the surface was present. They concluded that small PdO particles with a hemispherical crystalline structure produced a faster color change in the presence of hydrogen versus particles with a spherical structure. They also concluded that the more agglomeration of particles at the surface, the larger the color change produced.

Another study that was completed[8] investigated the influence that low operating temperatures had on the reaction rate of the hydrogen tape. This study was completed on a 3.6 mil thick Teflon tape composed with a 3 wt% of the hydrogen sensing pigment. Initial studies were done at -50°C but reacted too slowly. Therefore, triplicates

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were run at the temperature of room temperature, 0°C, and 20°C. According to the data collected and graphs produced, the average reaction rate was directly influenced by the operating temperature where a slower reaction rate was observed the lower the temperature.

In this same study, aerogel was added to the hydrogen sensing tapes to determine if it would aid in increasing the reaction rate at the lower operating temperatures. In order to complete this study, Cabot Corporation's Nanogel Aerogel 102 was incorporated into tape made of Versify 2300 (Dow Corning Chemical Corporation) with a 1.5 wt% of the hydrogen sensing pigment. The percentage of aerogel incorporated into the tapes included 0, 2.5, and 10 wt%. After exposing each tape to 100 % H_2 at 2.4 psig and analyzing the data, it was found that the incorporation of aerogel into the hydrogen tape increased the reaction rate at lower operational temperatures.

The final topic addressed in this same study tested the durability of flame resistant RTV. Initial laboratory testing of durability of flame resistant RTV was conducted on a tape fabricated with Dow Corning Silicone RTV SE 9189 L White with a 3 wt% of the hydrogen sensing pigment. By using a cable tie, the tape was placed on a piece of tubing containing running stream of LN_2. The stream of LN_2 ran for 30 minutes, exposing the tape to the cryogenic temperatures that would be experienced during a launch. After exposure to the LN_2, the tape was removed and inspections showed that the cryogenic temperatures did not structurally damage this tape. A tape made of Dow Corning RTV Sealant 739 was placed at the launch pad during the initial cryogenic loading for STS-133. This tape did not withstand the extreme cryogenic temperatures and tore apart. After laboratory studies were completed, it was determined that the cause for tearing was due to the added stresses of wrapping the tape too tightly around the flanges on the hydrogen lines. When this same laboratory testing was done on the tape composed of Dow Corning Silicone RTV SE 9189 L White, it was found that this material also tore if the tape was stretched too tightly while being exposed to cryogenic temperatures. These findings were taken into consideration when placing the final hydrogen tape at Launch Pad 39A for the launch of STS-133 on February 24, 2011.

III.   STS-133: Discovery

Figure 4. Flanges on Pad Slope where H₂ Tape was placed

For the final launch of space shuttle Discovery (STS-133), a tape using Dow Corning Silicone RTV SE 9189 L White was made with a 3% concentration of hydrogen sensing pigment. Four 100g batches were made and were made to a thickness of 35mils.

The tape was deployed on February 18, 2011 where it was placed on flanges of the hydrogen lines at three different sites on Launch Pad 39A – the Tail Service Mast (TSM), the Hydrogen Sphere, and the launch pad slope (Fig. 4). It should be noted that the TSM provided a slightly different environment for the hydrogen tape as the TSM presented an inert environment. It was made sure that the tape was not stretched too tightly in order to avoid tearing of the tape. Following the launch of Discovery on February 24, 2011, the hydrogen tape was inspected and removed from the flanges on March 7, 2011 for analysis.

The tape that was deployed at the TSM remained beige indicating that there was no exposure to hydrogen during the launch. This tape also remained completely in-tact indicating no material failure. The tape that was deployed at the hydrogen sphere also remained beige in color; however, due to the cryogenic temperatures experienced during the launch, the tape at the hydrogen sphere showed signs of cracking. The tape that was deployed at the pad slope showed signs of discoloration and extreme signs of material failure. Two pieces of tape were placed at two neighboring flanges at this location. Of the two, one piece was completely gone after the launch. One small section of the missing piece of tape was recovered from the field and showed the same signs of discoloration as the piece that remained on the hydrogen lines. The discoloration that occurred was not due to a hydrogen leak, however. The discoloration occurred in a spotting matter leading to the conclusion that the discoloration happened because of exposure to the SRB residue from the launch.

IV.   Future Work/ Recommendations

It was determined that the Dow Corning Silicone RTV SE 9189 L White was a suitable silicone matrix for hydrogen tape. It allowed for successful incorporation of the hydrogen sensing pigment and was not affected by UV

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radiation. It passed the flammability and electrostatic discharge tests. The only aspect where this tape failed was the ability to withstand the cryogenic temperatures for long durations. It is suggested that future studies be conducted on including a fabric layer to the silicone matrix in order to better withstand these cryogenic temperatures and to resist cracking and tearing.

Chapter 3: In Situ Resource Utilization

I. Introduction

One problem that NASA often faces when thinking about extended human presence on the Moon and planetary missions to Mars and beyond is how to supply the necessary raw materials such as oxygen, water, and fuel. These raw materials, if not supplied at the destination site, can greatly increase the costs and risks involved with these missions as they would need to be provided on-board the spacecraft, prior to liftoff. In Situ Resource Utilization (ISRU) is the process of making these raw materials by using the natural resources found at the destination site.

The lunar surface, in particular, has been the subject of many ISRU research efforts, especially at KSC and MSFC. Lunar regolith is composed of a variety of substances including oxygen, silicon, and a variety of metals (i.e. Fe, Al, and Ti). By performing different kinds of chemical processes on the regolith, scientists have been able to isolate the various substances and reuse them towards producing the raw materials, as mentioned above, that will allow extended human presence in space. The next few paragraphs will explain some past research that has been completed and the conclusions that have been made based on this research. These past research projects pave the way towards future endeavors to optimize production of these raw materials.

If the oxygen present in the lunar soil is isolated, it can be used as an avenue for human life support and as a propellant for the space vehicles. The oxygen can be extracted by various chemical means, but a previous study[3] has given reasons as to why molten oxide electrolysis (MOE) is the most practical option. One reason is when compared with other electrolytic processes, MOE is not highly sensitive to its feedstock composition. This feature offers an un-paralleled versatility for similar O_2 productions at all landing sites. Secondly, because the electrolytic process uses the regolith melts, the highest solubilizing capacity and lowest volatility is seen. These two features guarantee the highest productivity and simplest reactor design. No other electrolyte can offer these advantages. MOE also does not require the use of any consumable reagents resulting in a one-step extraction process. Finally, MOE offers the opportunity to selectively extract products from the regolith according to the solubility of the oxides. These selectivities are expressed in terms of the free energy of the oxides formation. This study also completed some modeling of MOE using BUNDLE (Bridgman Unidirectional Dendrites in Liquid Experiment) hardware to give the following anodic reaction[3]:

$$O^{-2} \rightarrow 2e^- + \tfrac{1}{2}O_2$$
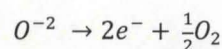
This reaction was modeled to extract 125.7g of O_2 by electrolysis running at 2 Amperes and 5 Volts. From this model, further calculations were done to determine the amount of time it would take to extract the oxygen. It was calculated that it would require 4 hours to extract 1 gram of Oxygen at 1 Volt. The following mathematical formula was used for these calculations[3]:

Figure 6. Reactor Design produced in the COSMOL Mutliphysics™ software

$$W_{O_2} = \frac{MIt}{nF}$$

Where M is the molecular weight, I is the current, n is the valence number, and F is the Faraday constant.

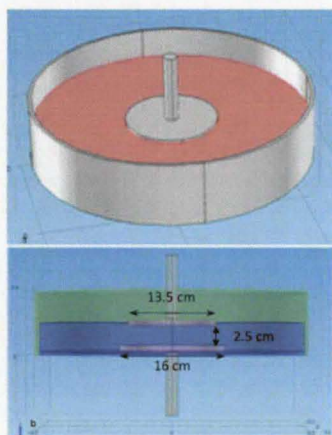A recent study published[4] on oxygen extraction from lunar regolith using MOE completed a dimensional analysis on an MOE reactor design. The goal of this study was to design a self-heating reactor that could produce enough Joule heat to create the molten products and maintain that molten mixture throughout the MOE process. The Joule heat that would create and maintain the molten bath would be produced by the thermal energy created by passing an electric current between the electrodes during the electrolysis process. A reactor of this design would

Figure 7. Preliminary Ionic Liquid Electrolysis Flow Chart

greatly reduce the external energy needed and would no longer be a necessary design component. Dominguez, J.A., et.al. produced the reactor design in Fig. 6 using the COSMOL Multiphysics[TM] modeling software[4]. It was concluded that Joule heating was a sufficient method for producing heat to keep a molten mixture molten. However, when a model was made to simulate a "cold start" (where the material is not molten yet), Joule heating was not able to provide enough heat to make the mixture molten. An external heating source would be needed to get the process started. Once started, Joule heating can then be utilized as a sufficient method to maintain enough heat to keep the mixture molten.

Other studies have been conducted on extracting silicon from the lunar surface in order to fabricate solar photovoltaic cells. It is suggested that the silicon from the lunar regolith can be used in conjunction with the vacuum-like atmosphere to initiate direct vapor deposition of the silicon onto thin film materials. These fabricated solar cells would then be used to provide energy "around the Earth/Moon system so every spacecraft we build doesn't have to carry its own power source", as explained by previous NASA Administrator, Michael Griffin[3].

An in-depth discussion of the silicon extraction and solar cell fabrication advancement will not be explained here; however, research is still ongoing in these subject areas. For the purposes of this research paper, it is the oxygen extraction via molten oxide electrolysis that is of key interest.
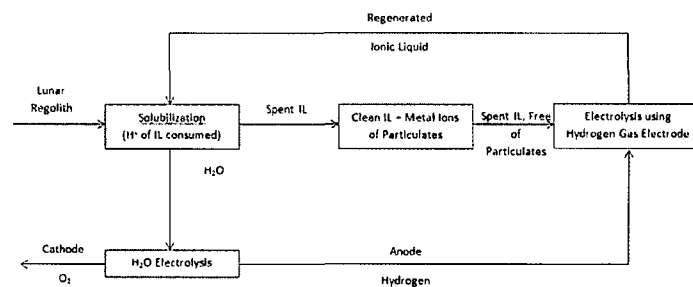
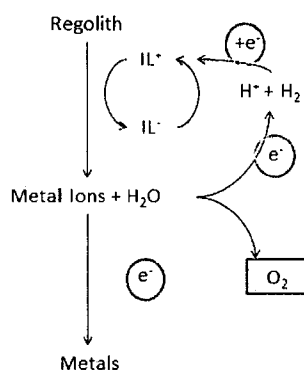## II. Summer Research Project

Figure 8. Preliminary Chemical Flow of Ionic Liquid Electrolysis

Advances in the world of ISRU research are always happening. One of the most recent advances was the development of a new method of extracting oxygen and metals from regolith of the Moon, Mars, and asteroids. At the Marshall Space Flight Center's ISRU laboratory, methods are being developed to perform methods of electrolysis by using ionic liquid electrolytes. By using the ionic liquid electrolyte, the regolith would be able to be dissolved at temperatures less than 200°C, which is much lower than temperatures needed for MOE.

When performing electrolysis using ionic liquid electrolytes, the first step occurs in an extraction chamber where the product is water and the by-product is the ionic liquid "frame", meaning it no longer contains hydrogen. The water will then be electrolyzed separating the oxygen and hydrogen. The current problem with this method is that fresh ionic liquids need to constantly be resupplied to dissolve the regolith, as the spent ionic liquid no longer contains the needed hydrogen for this process to be carried out.

As a participant in the 2011 NASA Academy and a researcher under the guidance of Dr. Peter Curreri at Marshall's Space Flight Center, I will be working towards resolving this problem. During the months of June through August 2011, I will be helping design a prototype laboratory system to extract space resources using the methods of electrolysis with ionic liquids. The main design challenge will be to design a closed loop system that will be able to use the hydrogen extracted from the water to regenerate the spent ionic liquid. The regenerated ionic liquid will then be recycled back to the extraction chamber so that more regolith may be dissolved and the electrolysis process can continually be going. A preliminary process flow schematic of the recycling process flow diagram can be seen in Fig. 7 and a preliminary chemical flow schematic can be seen in Fig. 8.

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Acknowledgments

I would first and foremost like to thank my mentor, Dr. Luke Roberson, for providing me with this amazing internship opportunity. In the few professional experiences I have had as a college student, I have not had a mentor care so much about his intern and their future. Luke has been so willing to make sure I get the most out of this internship opportunity. He has helped me discover where my true research interests lie and have helped me develop as a young professional. He has taught me some many of the lessons on how succeed in this business world.

I would also like to give a special thanks to Megan Morford, Michele Birmele, and Dr. Mary Whitten who taught me about their research by allowing me to work alongside of them in the labs.

I would also like to thank all of the researchers in the Space Life Sciences Lab and the O&C who have made this internship one to remember.

References

[1]BioSurface Technologies Corp, *CDC Biofilm Reactor – Operator's Manual.*

[2]Bloem, J., "Fluorescent straining of microbes for total direct count," *Molecular Microbial Ecology Manual*, Vol.8, Kluwer Academic Publishers, Netherlands, 1995, pp.1-12.

[3]Curreri,P.A., Ethridge,E.C., Hudson,S.B., Miller,T.Y., Grugel, R.N., Sen,S., and Sadoway, D.R., "Process demonstration for lunar in situ resource utilization – molten oxide electrolysis", NASA/TM-2006-214600.

[4]Dominguez,J.A. and Sibille,L., "Multiphysics modeling for dimensional analysis of a self-heated Molten Regolith Electrolysis reactor for oxygen and metals production from space resources", *49th AIAA Aerospace Sciences Meeting*, Orlando, FL, 2011.

[5]Mohajeri,N., T-Raissi,A., Bokerman, G., Captain, J.E., Peterson, B.V., Whitten, M., Trigwell,S., Berger,C., and Brenner, J., "TEM-XRD analysis of PdO partciles on TiO_2 support for chemochromic detection of hydrogen", *Sensors and Actuators B*, Vol.144,Elsevier, 2010, pp.208-214.

[6]NASA-STD-3000B-Volume I, Ch. 7.

[7]Sibille,L., Sadoway,D.R., Sirk,A., Tripathy,P., Melendez,O., Standish,E., Dominguez,J.A, Stefanescu,D.M., Curreri,P.A., and Poizeau,S., "Recent advances in scale-up development of molten regolith electrolysis for oxygen production in support of a lunar base", *47th AIAA Aerospace Sciences Meeting*, Orlando, Fl, 2009.

[8]Whitten, M., "Report for multi-use hydrogen chemochromic detectors", 2011.